Measuring Variations in Mean Ocean Mass

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Satellite Observations of the Global Water Cycle

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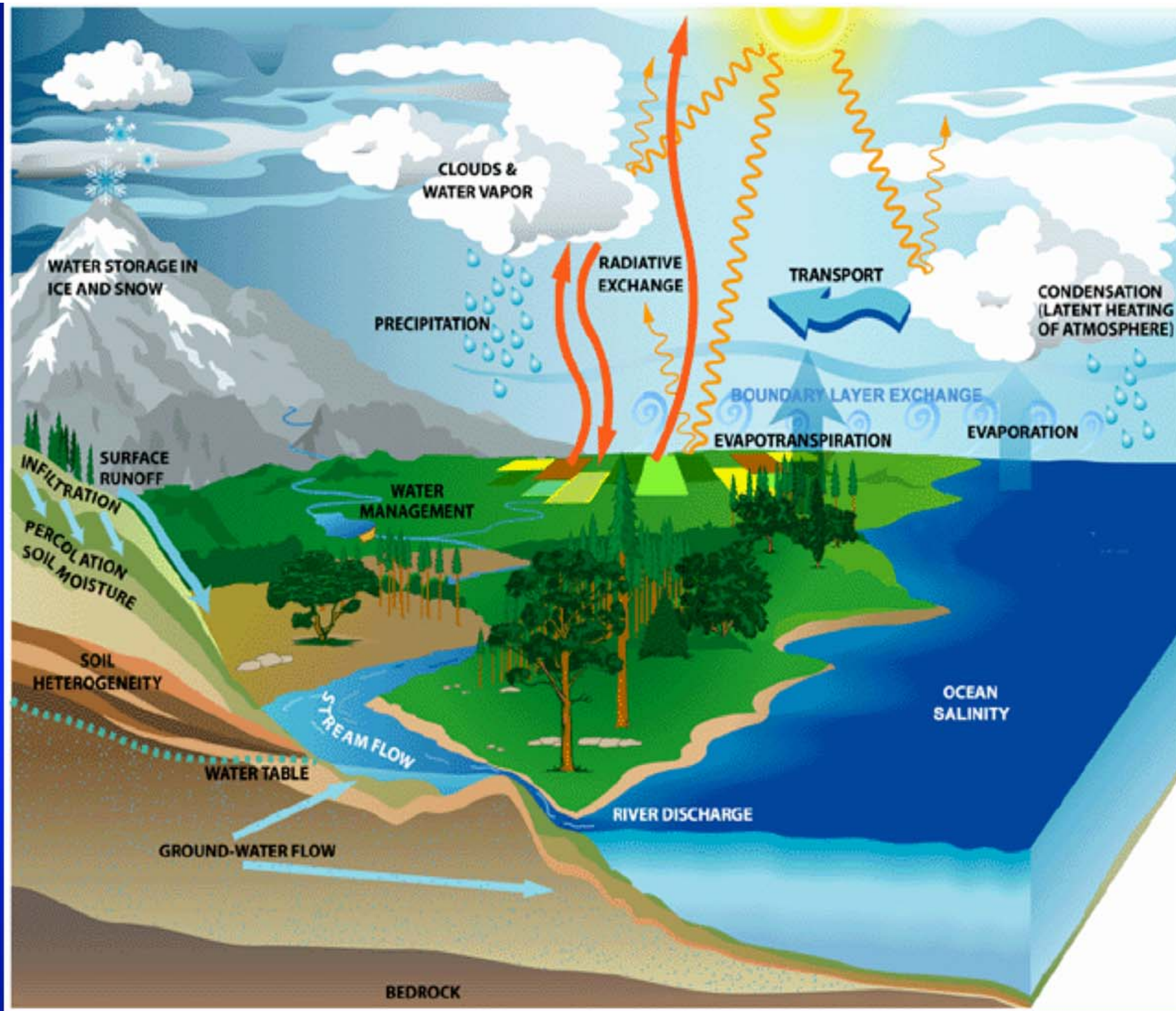
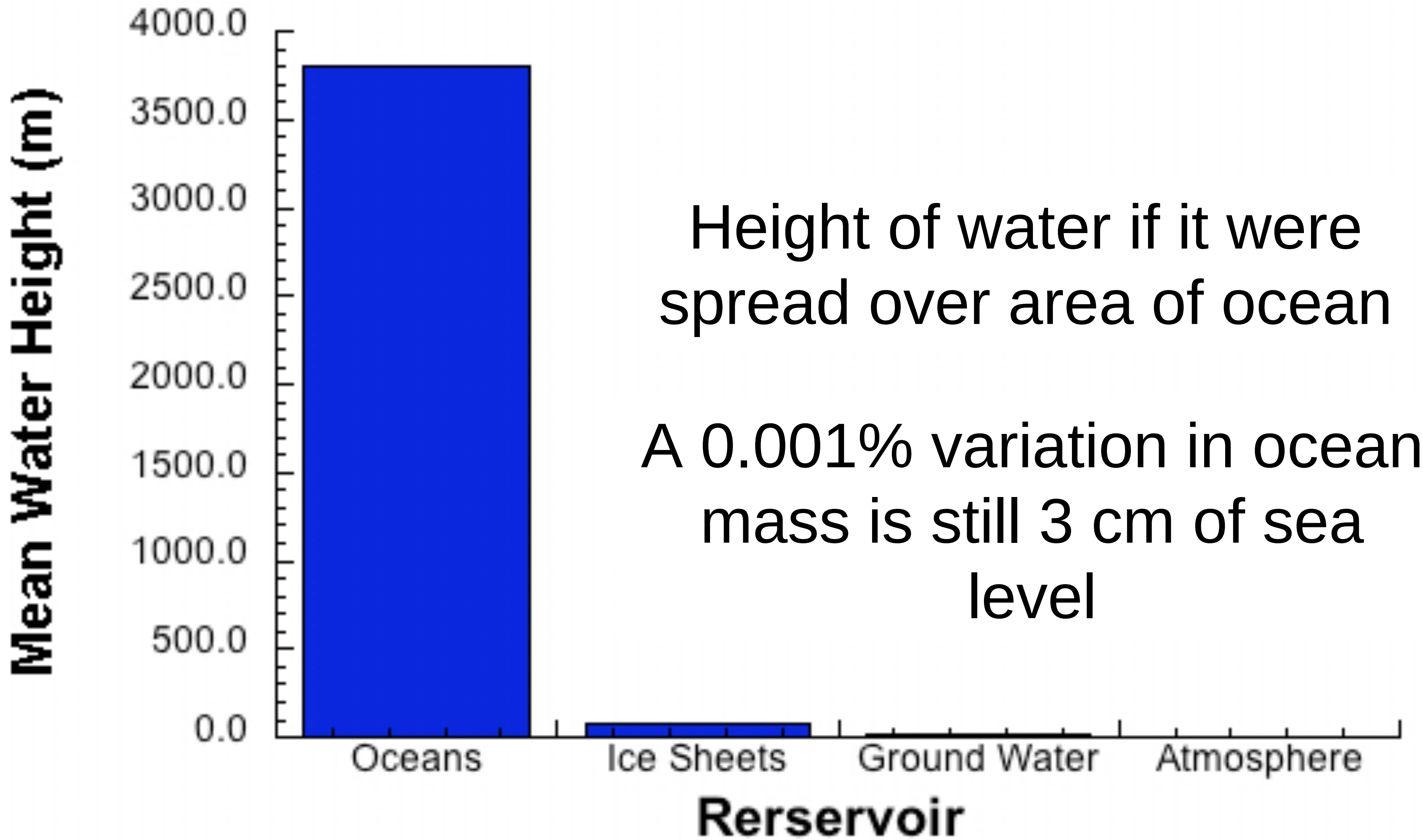
Irvine, CA



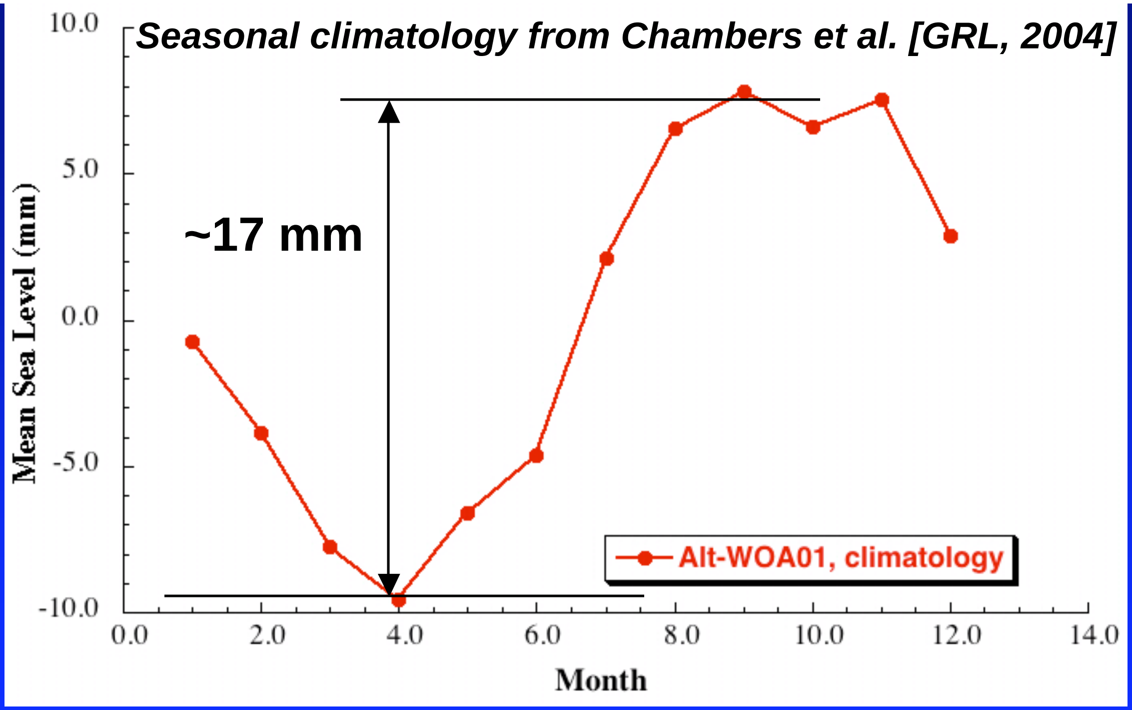
The Global Water Cycle

Putting it in Perspective



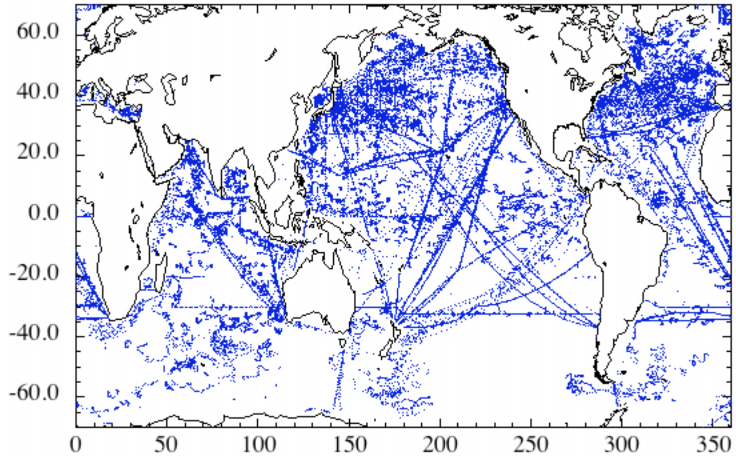
Height of water if it were spread over area of ocean

A 0.001% variation in ocean mass is still 3 cm of sea level

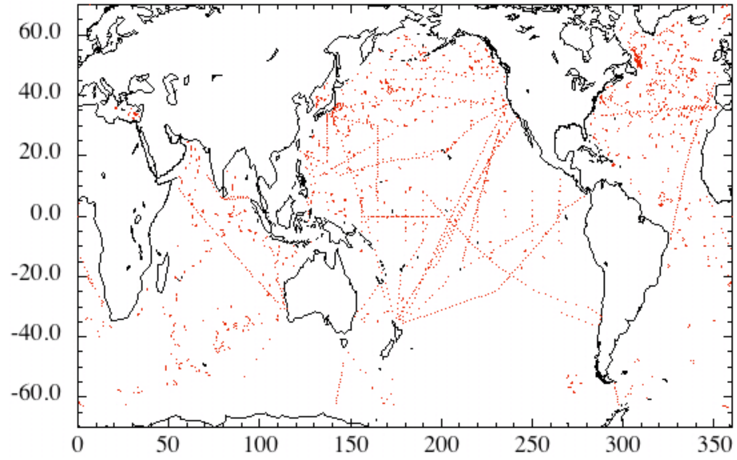


- Chen et al. [*GRL*, 1998] first showed there was a significant residual in GMSL that was not explained by thermal expansion/contraction

- This was linked to a regular, seasonal exchange of water between the ocean and continents by Chen and others [e.g., Cazenave et al., *GRL*, 2000]



“Best” Temperature Profiles From GTSPP

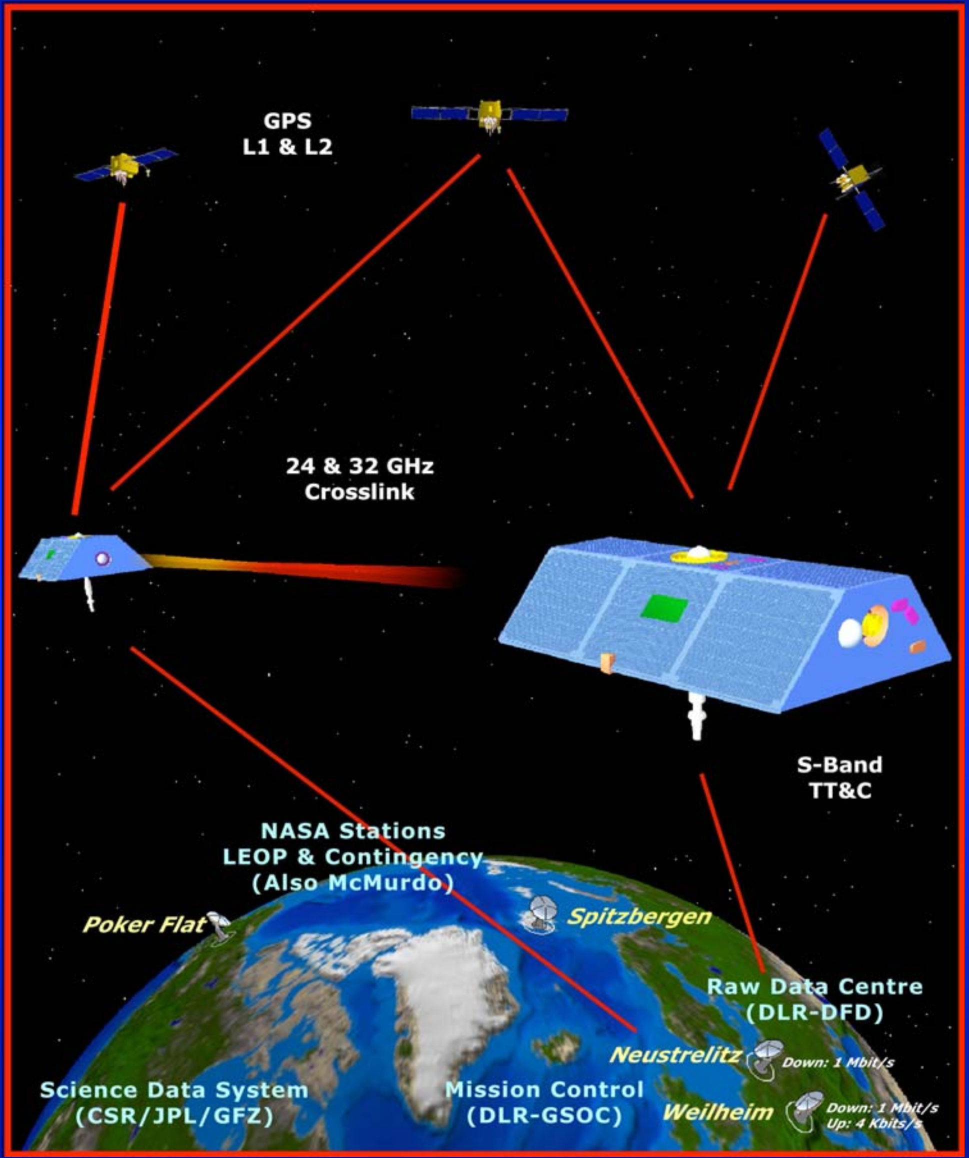


All of 2003

January 2003

- Combining altimeter and steric data gives an indirect measurement
- Most temperature measurements are made in the upper portion of the ocean (< 500 m)
- Ignores observations of temperature changes in deeper layers [e.g., Levitus et al., *Science*, 2000] that will be in altimeter measurement

Gravity Recovery & Climate Experiment (GRACE)



Science Goals

Measure time variable gravity field to detect changes in the water storage and movement from reservoir to another (e.g., from ice sheets to ocean)

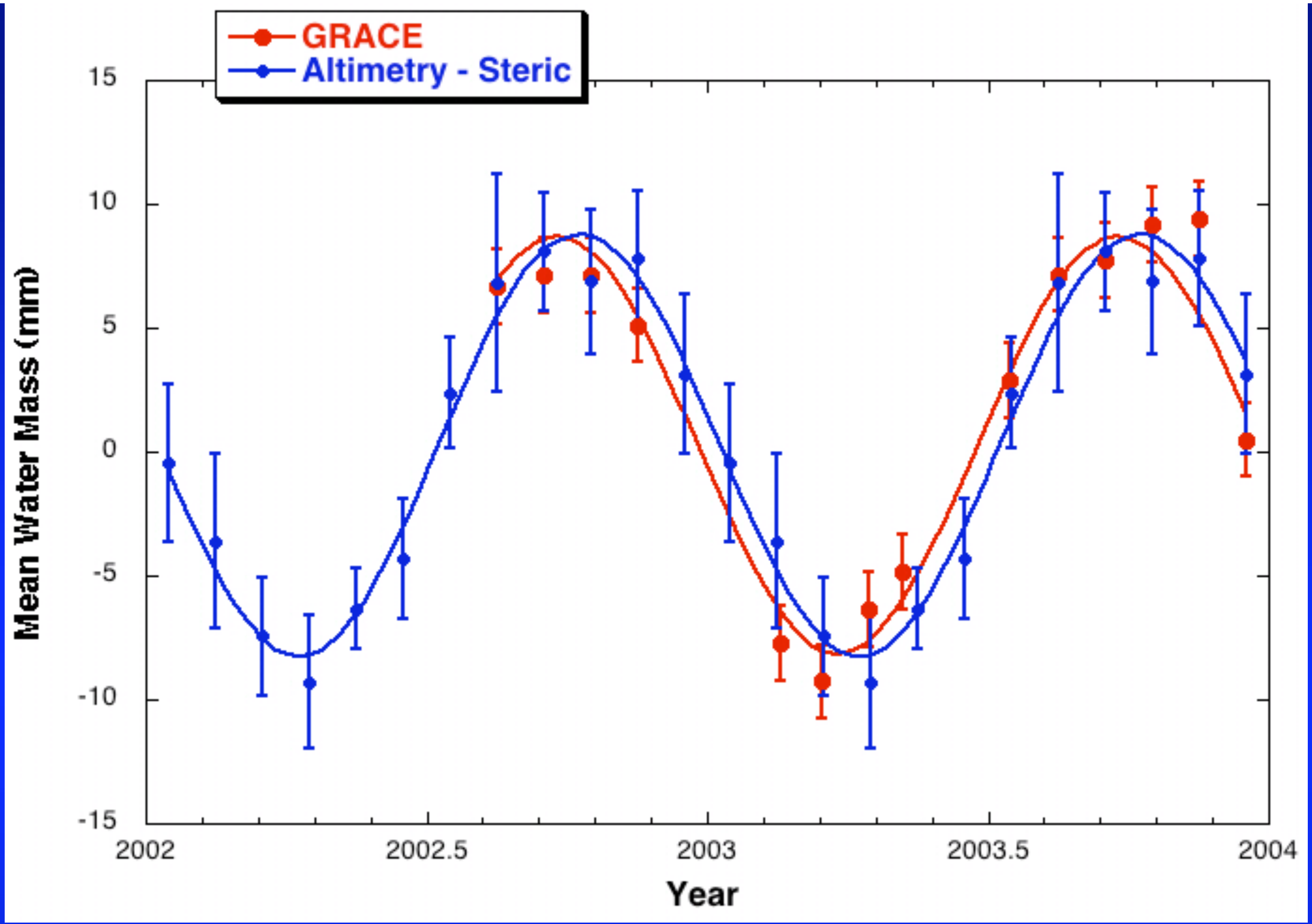
Mission

Joint NASA/German mission implemented by NASA and DLR (Deutschen Zentrum für Luft-und Raumfahrt) under the NASA Earth System Science Pathfinder Program.

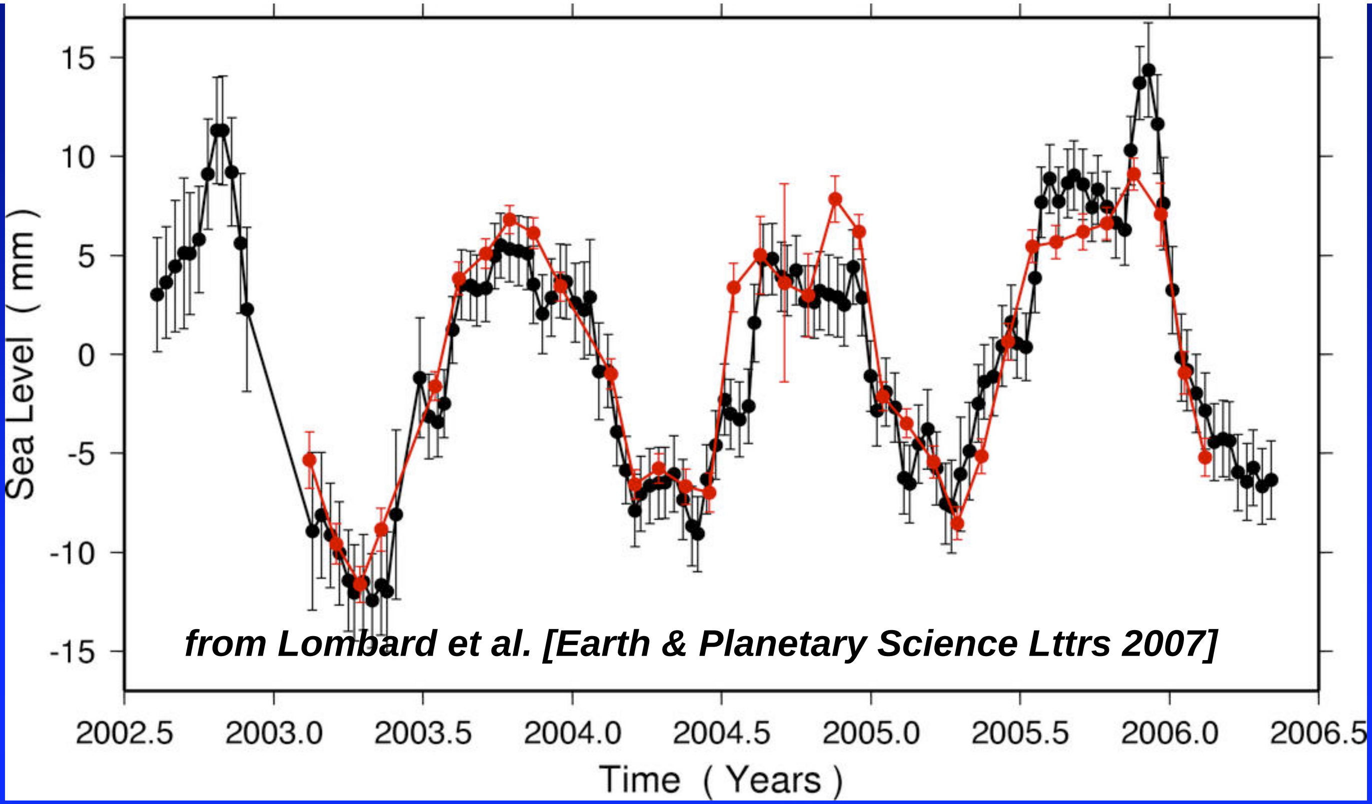
Science data processing by University of Texas Center for Space Research (UTCSR) and GeoForschungsZentrum (GFZ)

Orbit

Launched: March 17, 2002
Regular Science Data: August, 2002
Original Lifetime: 5 years
Recently NASA/DLR extended mission through 2009



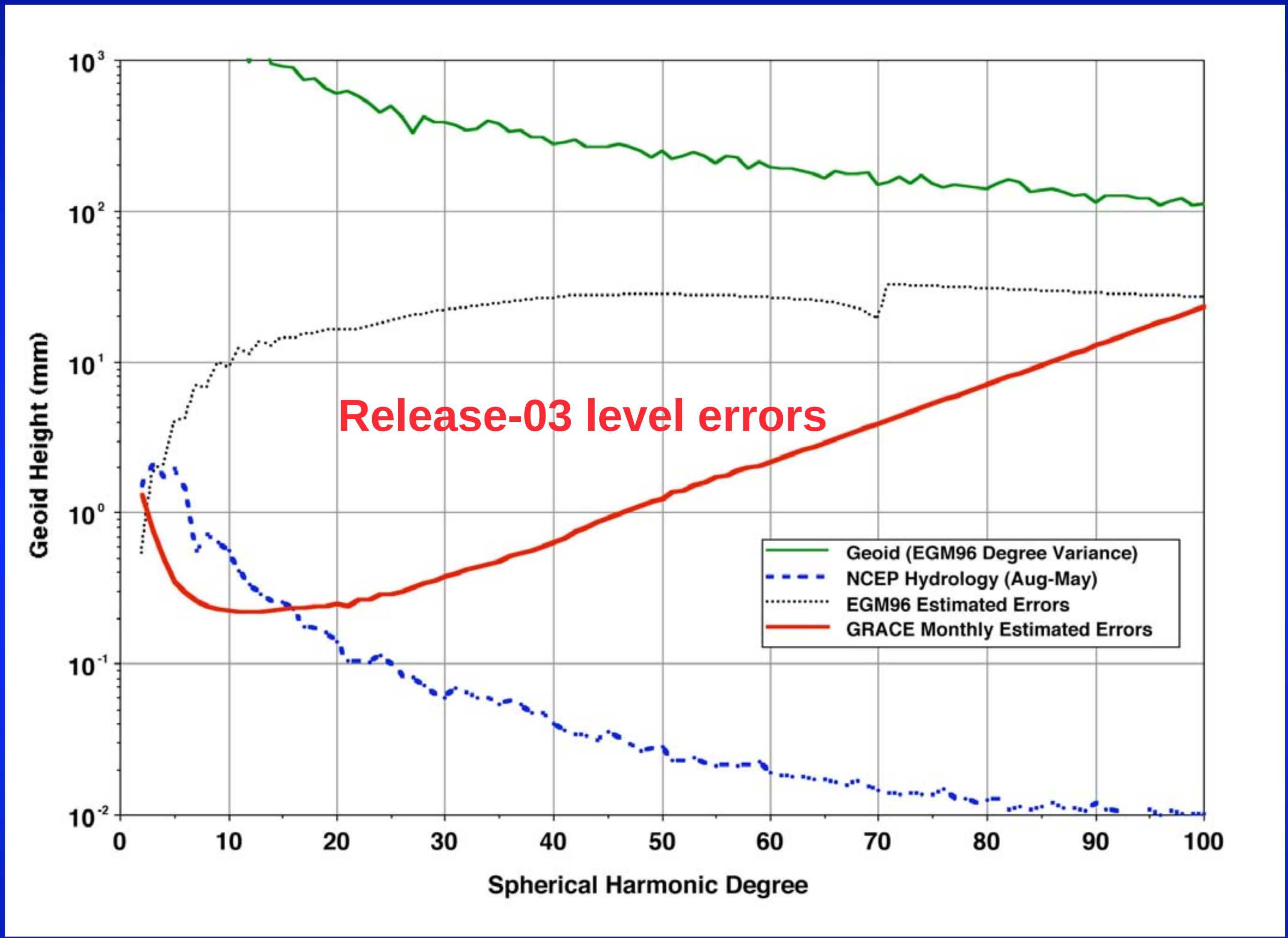
- Chambers et al. [*GRL*, 2004] first demonstrated that GRACE was capable of measuring the mean ocean mass, with an accuracy better than that of combining altimeter and steric data



- As the GRACE mission continues, we can begin to evaluate interannual and secular signals in ocean mass

- However, it is vital to understand the uncertainty of the measurement and how GRACE data are converted to mean ocean mass variations

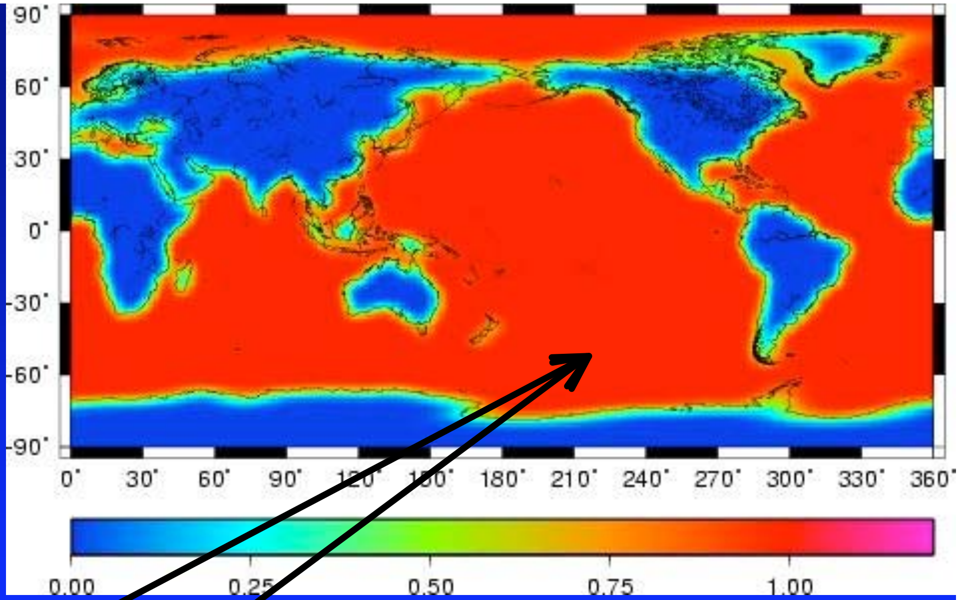
GRACE Errors



long wavelength short

- GRACE project produces a set of global gravity coefficients (ΔC_{lm}, ΔS_{lm}) every month

- Convert these to a time-series of monthly average water level (sea level) over a basin by

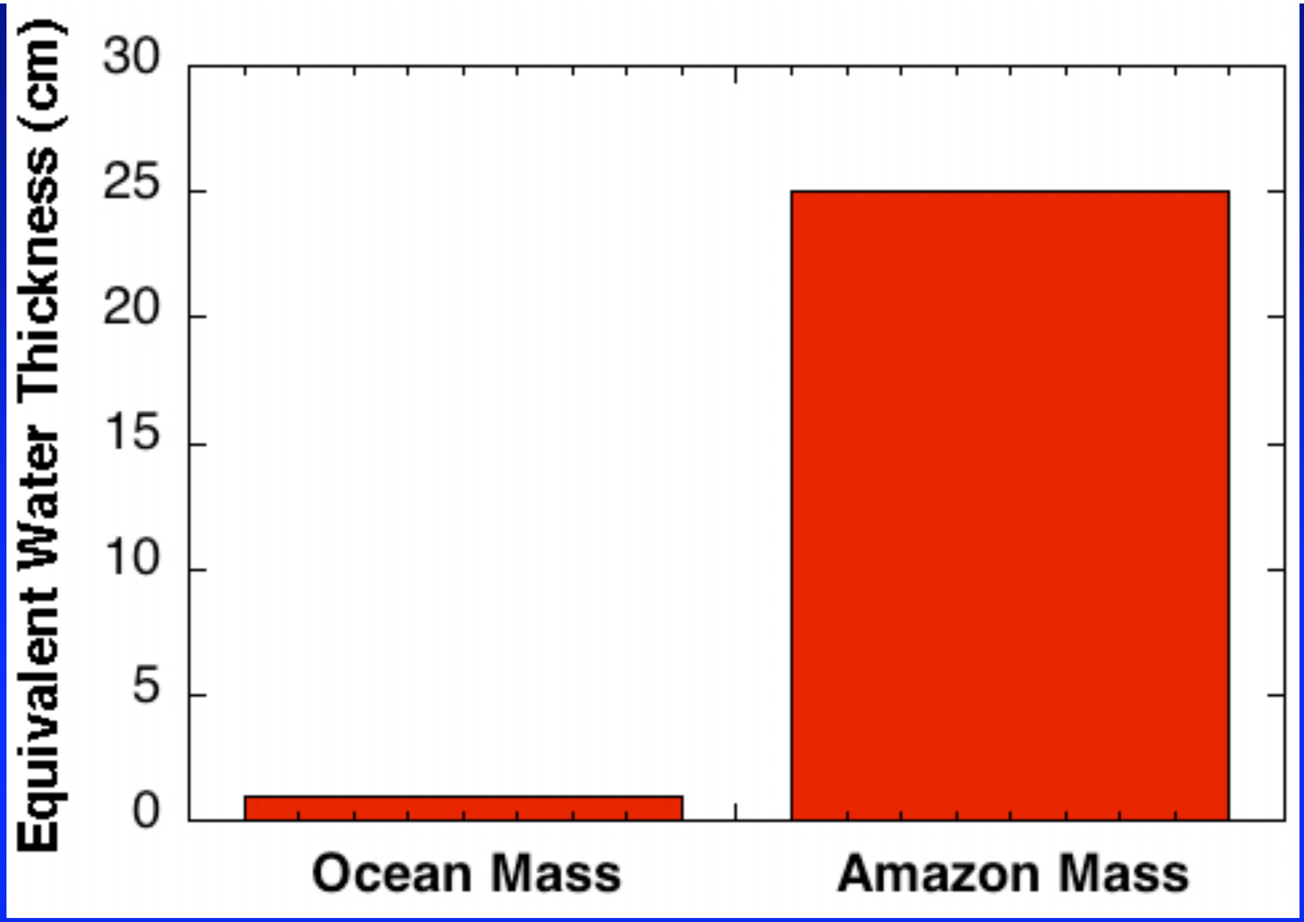


Ocean kernel

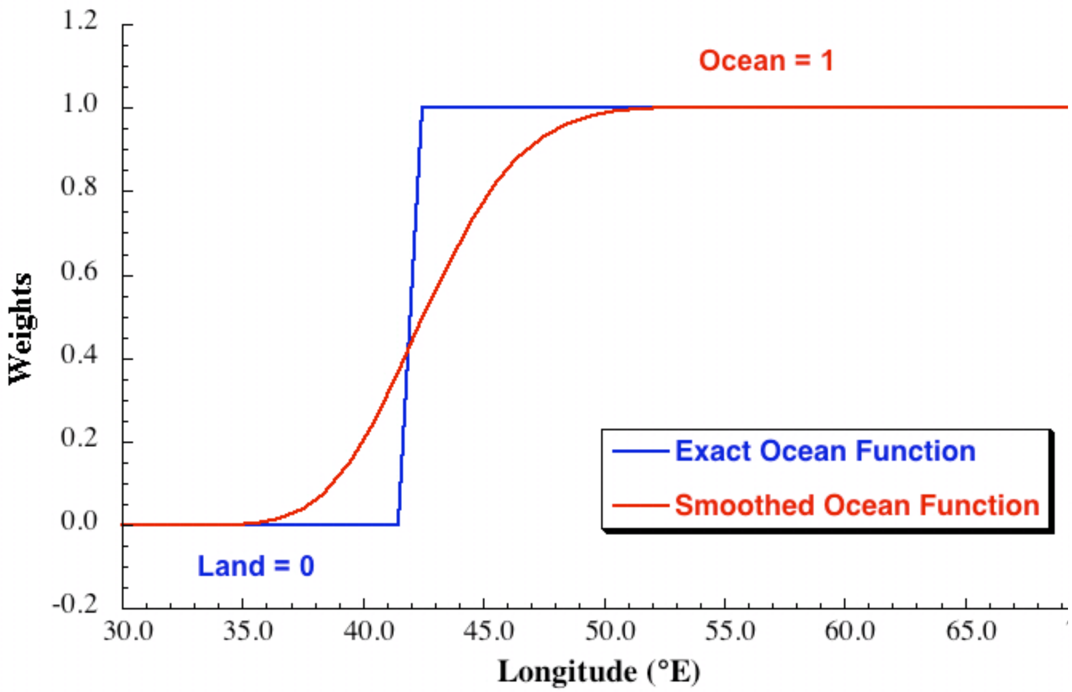
$$\Delta\eta_{basin} = \sum_{l,m} \frac{Q_l}{\Omega_{basin}} \left(W_{lm}^C \Delta C_{lm} + W_{lm}^S \Delta S_{lm} \right)$$

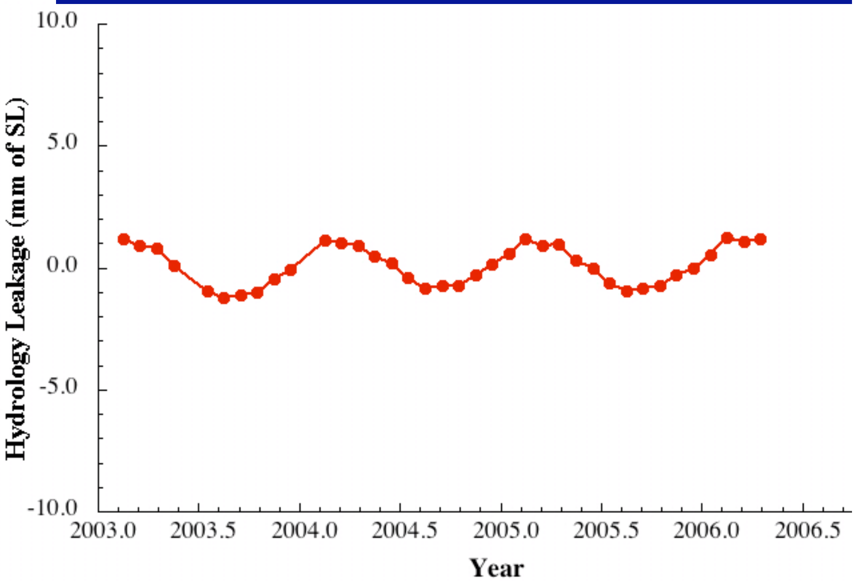
$$Q_l = \frac{a\rho_E}{3\rho_W} \frac{(2l+1)}{(1+k_l)}$$

- Coefficients of ocean "kernel" defined to spatially smooth GRACE gravity coefficients [Swenson and Wahr, *JGR*, 2002]

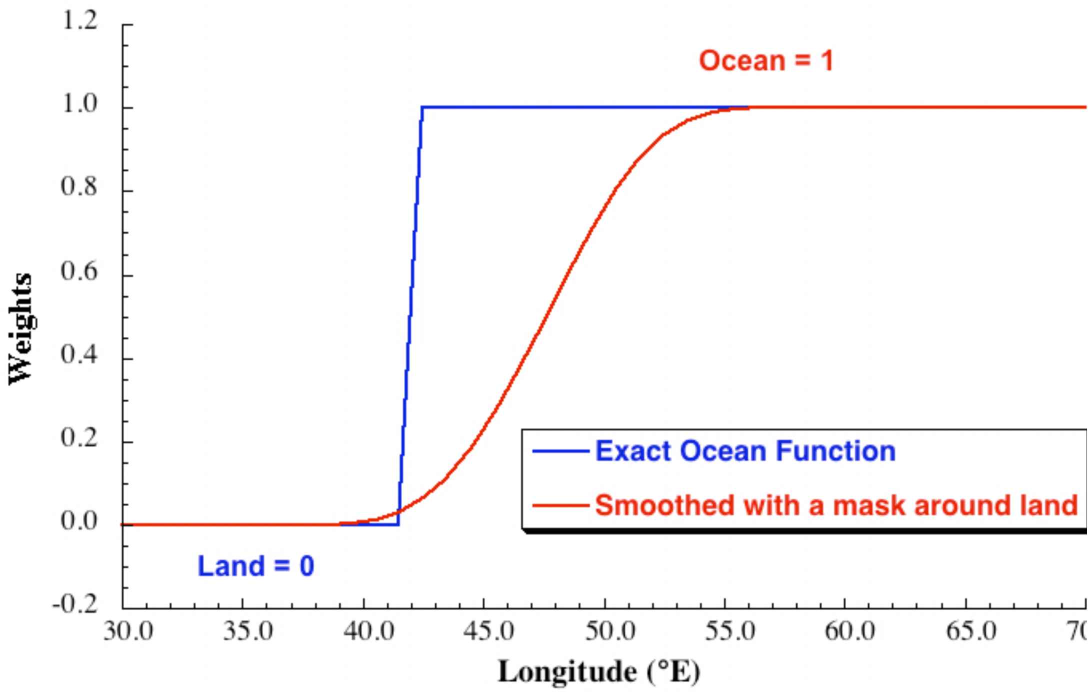


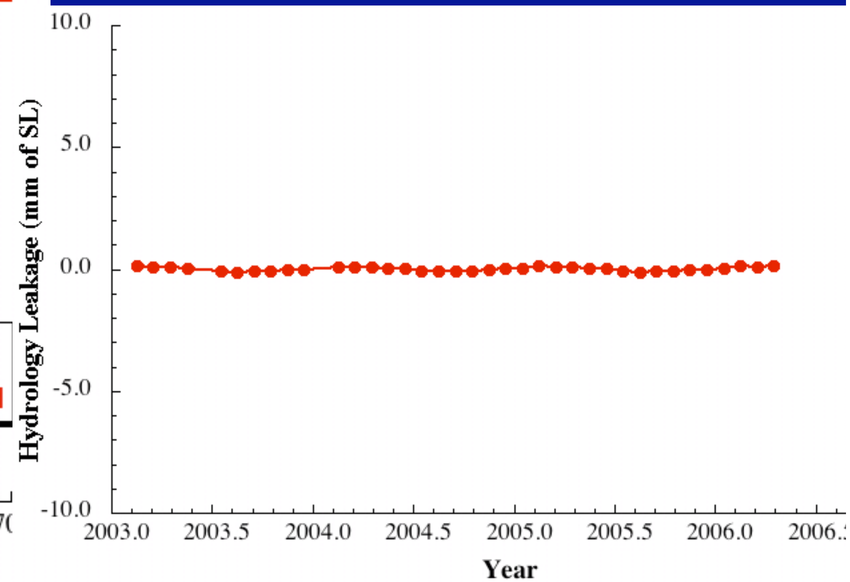
- Much larger mass variations over land can “leak” into ocean estimate if data are smoothed too much





- For this ocean kernel, some non-zero weights are given to data over land
- The large land signals can leak into estimates of ocean mass, and shift the estimated results away from the truth
- The leakage of hydrology (from the GLDAS NOAH model) for this kernel is about ± 1 mm, but with a systematic seasonal signal





- Here, we have also set ocean points within 300km of land to zero, so almost no land values are given weight when smoothing

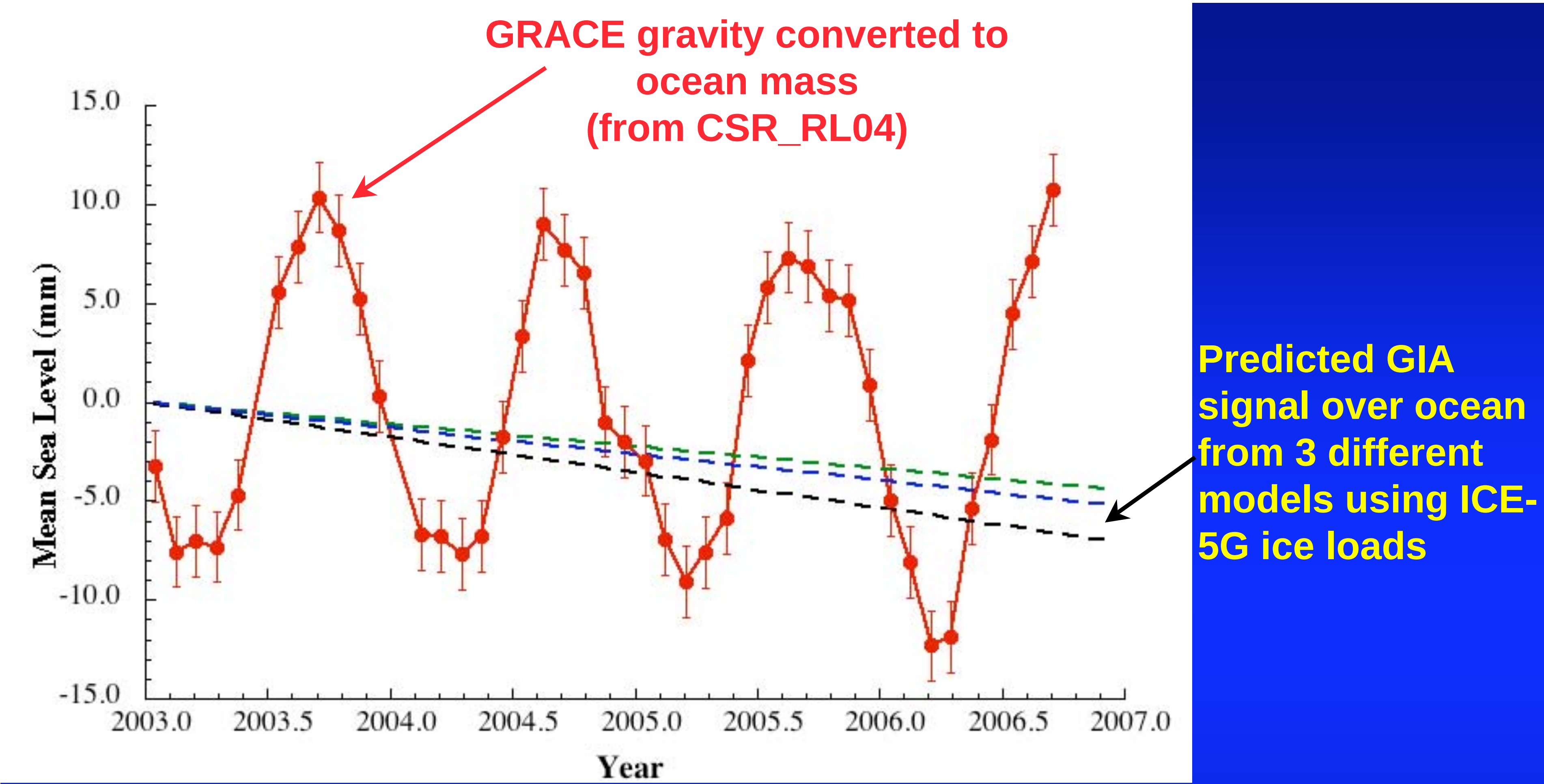
- The leaked hydrology is minimal (< 0.1 mm of MSL)

Leakage from Ice Sheet Melting

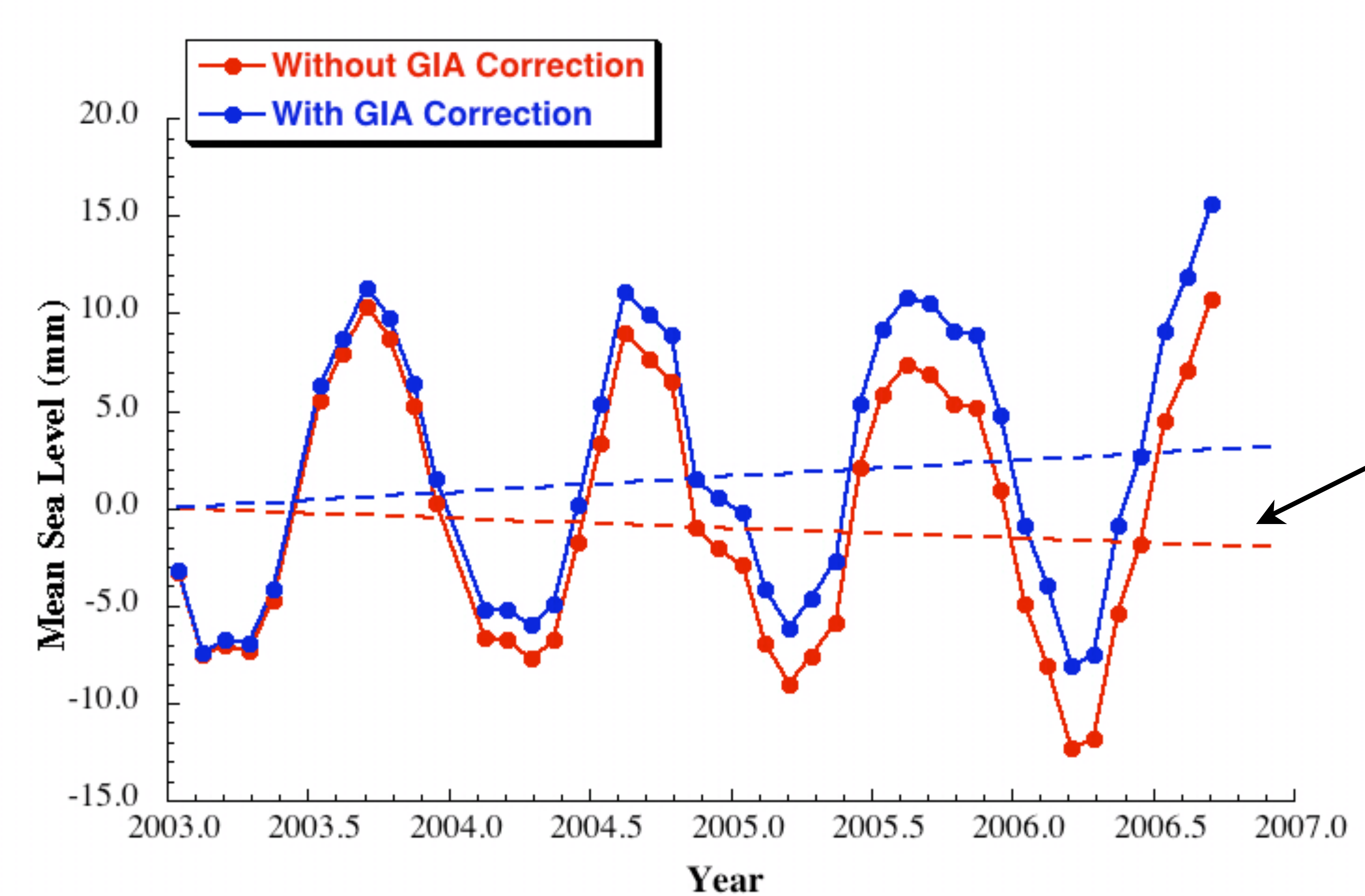
- Secular trends in mass loss from ice sheets and glaciers can also leak into GRACE estimates of ocean mass

- Will cause an error that is also a trend

- Based on a simulation using recent observations of Greenland, Antarctica, and mountain glacier melting, Chambers et al. [*GRL*, 2007] estimated that this would cause GRACE to underestimate the secular trend in ocean mass by **0.17 ± 0.08 mm/year**.



- GRACE measurements include the gravitational effects of secular glacial isostatic adjustment (GIA)
  - » GIA Models disagree at the level of ± 0.5 mm/year of sea level depending on the ice history and solid Earth model used



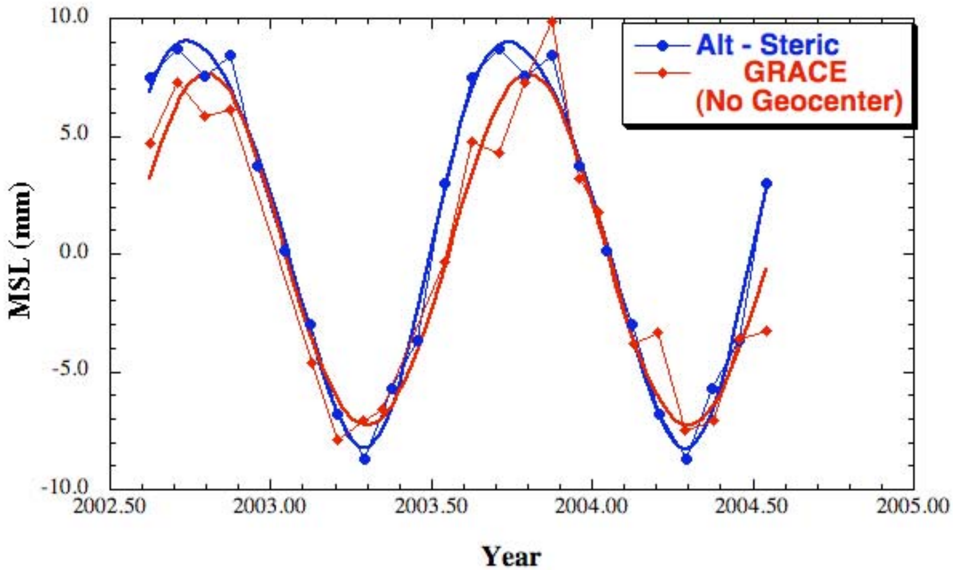
Trends (estimated along with bias + seasonal periods)

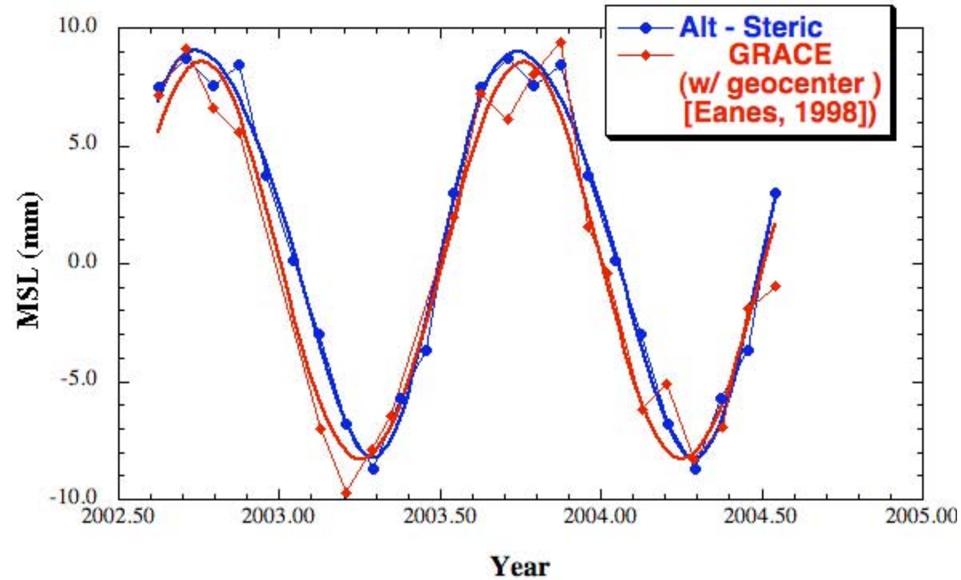
- Adding GIA correction to GRACE changes interpretation of mass trend significantly
- Over the last four years, ocean mass has been increasing

Geocenter Variations

- GRACE satellites orbit instantaneous mass center of Earth, so use this as the center of the reference frame
- Ideally, want to measure ocean mass in a terrestrial reference frame, where the frame center ≠ instantaneous mass center
- To translate from GRACE-frame to terrestrial frame, we have to model/measure these *geocenter* variations

from Chambers et al. [GRL, 2004]





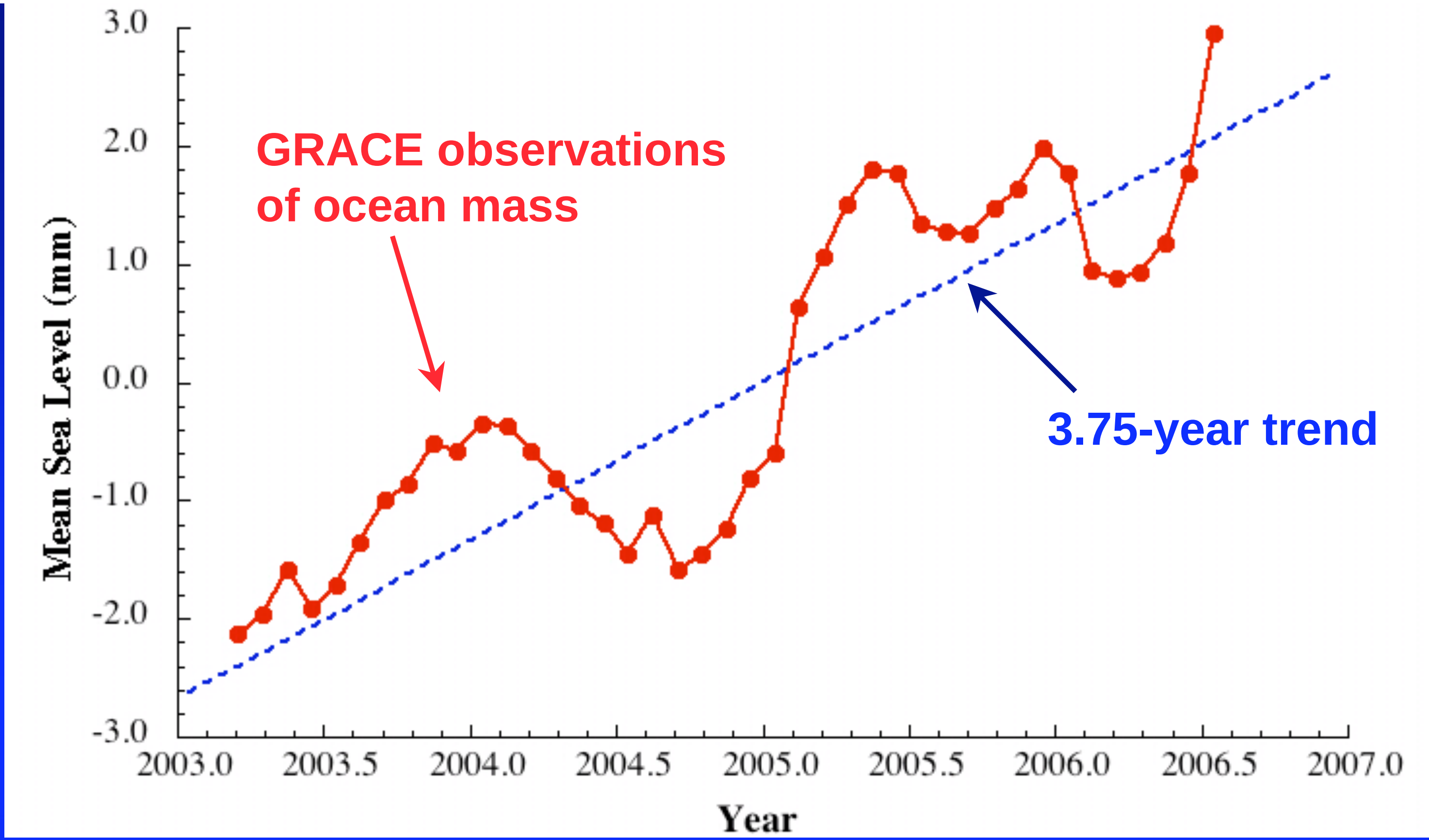
GRACE w/o geocenter model **GRACE w/ geocenter model**

- Correction can be made for at least the mean seasonal variation
- A simulation of secular geocenter from only ice melting [Chambers et al., GRL, 2007] suggests that GRACE may be underestimating ocean mass rate by **0.36 ± 0.18 mm/year** when geocenter is ignored

Ocean Mass Rate (2003 to 2006)

	Ocean Mass Rate (mm/year of SL)
Raw GRACE measurements[1]	-0.51
after correcting for GIA[2]	0.81
after correcting for leakage from ice[3]	0.98
after correcting for secular geocenter[3]	1.34
Final rate estimate with uncertainty	**1.34 ± 0.65[4]**

1 - CSR_RL04, Jan 2003 to Sept 2006, estimated with bias + seasonal variations
2 - Using model from A. Paulson with a mean ocean rate = -1.34 mm/year
3 - From simulations [Chambers et al., GRL, 2007]
4 - RSS of formal error and uncertainty for GIA, secular leakage from ice, and secular geocenter from ice melting. This does not account for leakage from interannual variations or geocenter from signals other than ice melting

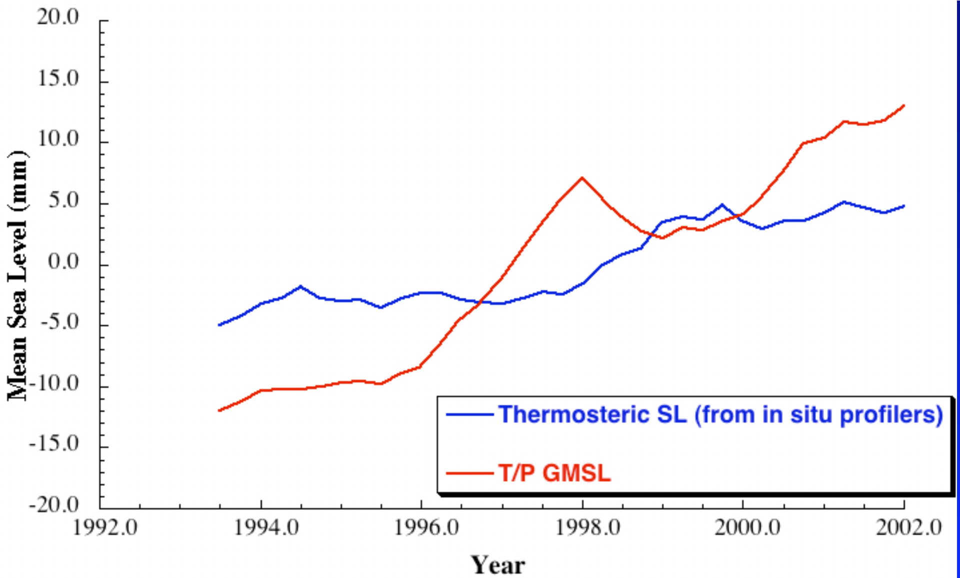


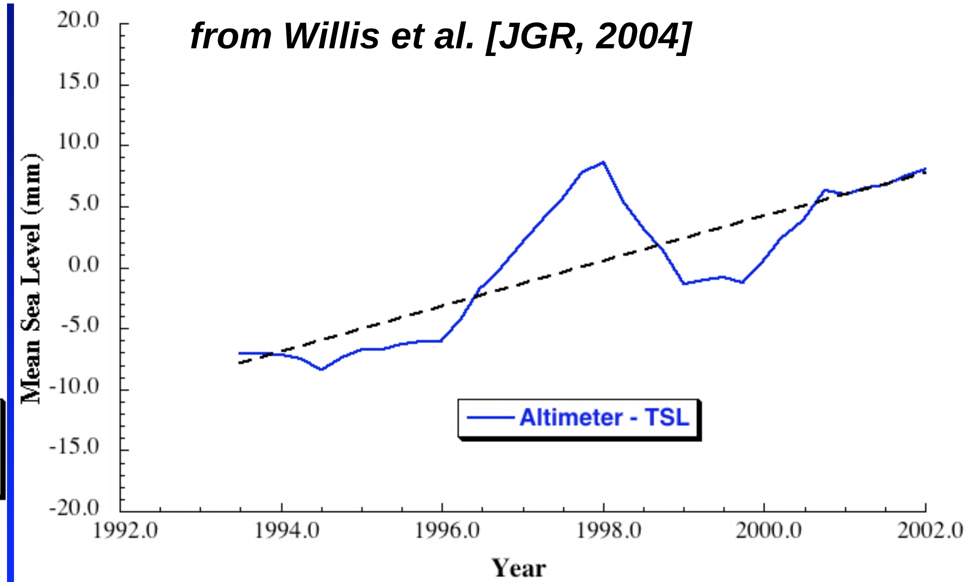
- Obvious variations in ocean mass with period > 1 year and < 3 years
- Are there variations with period > 4 years?

Conclusions

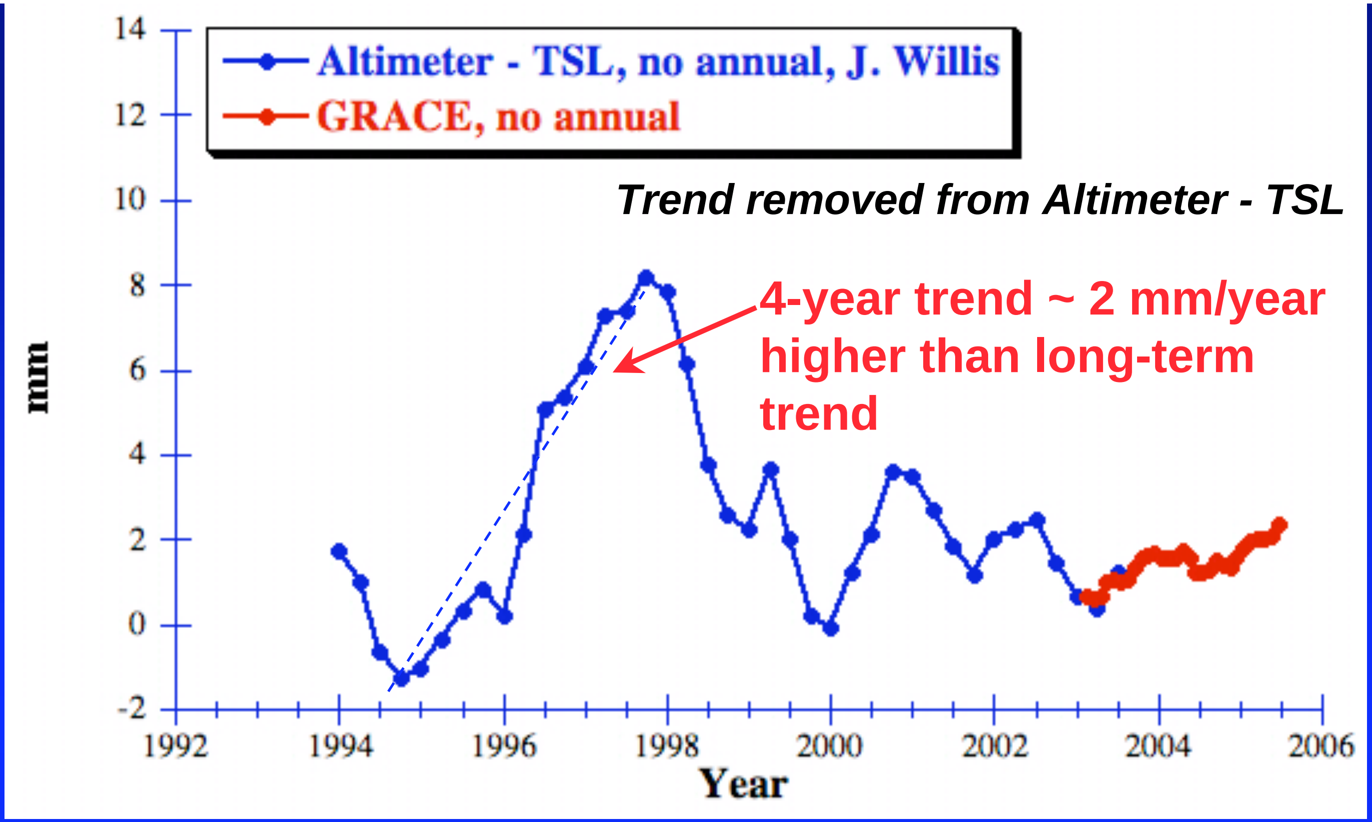
- We can now measure monthly variations in ocean mass accurately at the 2-3 mm level from GRACE
- Ocean mass has been increasing at a rate between 0.7 and 2 mm/year of equivalent sea level over the last 4 years
- Still uncertain how much of this is purely secular and how much is interannual

Extras





- Several investigators began to look for interannual ocean mass variations and evidence of ocean mass trends in the SL measurements [e.g., Chambers et al., *GRL*, 2000; Cabanes et al., *Science*, 2000; Miller and Douglas, *Science*, 2004; Willis et al., *JGR*, 2004].



With 1-year smoothing

- We have limited knowledge of interannual variations in ocean mass
- Some evidence of ± 4-5 mm variations at ENSO periods (4-7 years)